# Project Deliverable D:
# Conceptual Designs

*Submitted by*


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# Abstract

The report develops three solutions, based on the previously identified design, the prioritized design criteria and the product bench marking. These were further refined into a final solution. After identifying the design criteria and the needs of Mr.  Enendu, our team came together to create conceptual designs to fulfill the needs of the clients. For each solution there was subsystems required. Our team identified a toral of 4 sub systems. These subsystems address the problem statement and design criteria. The solutions were analyzed and compared to the original design; they were broken down into diagrams. The benefits and functionalities of these systems were also identified. Overall, the three solutions were found, debated and ranked. From these steps, a final solution was chosen to further pursue our prototype.

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# 1 Introduction

This report details the generation of three unique solutions based on the interpreted client needs from our preliminary client meeting. They expressed a need for a cost effective, portable, automated, environmentally friendly, and higher functional product. This is important because there are many automated devices that can reach the desired temperature however, most of them are expensive, not portable, and they have additional cost on the energy sources that cause greenhouse gases.

In the concept generation phase, the team individually conceptualized modified concepts and components for each subsystem to address the problem statement and design criteria. Following the creation of four subsystems, the ideas were compared to select the most appropriate solution from each prototype subsystem. These subsystem concepts were then grouped to produce three refined solutions that were further analyzed, and then streamlined into figures and tables. These three conceptual designs were evaluated against one another, and the superior solution was determined to address the client's needs most accurately.

# 2 Conceptual Design: Sub-System

It is necessary to define the overall system where Figure 1 and Figure 2 describes the process of the conceptual design. The overall system consists of different sub-systems that essentially approaches how the system cools and heats. Based on the flow charts in Figure 1 and 2, the three initial sub-systems will incorporate these requirements.

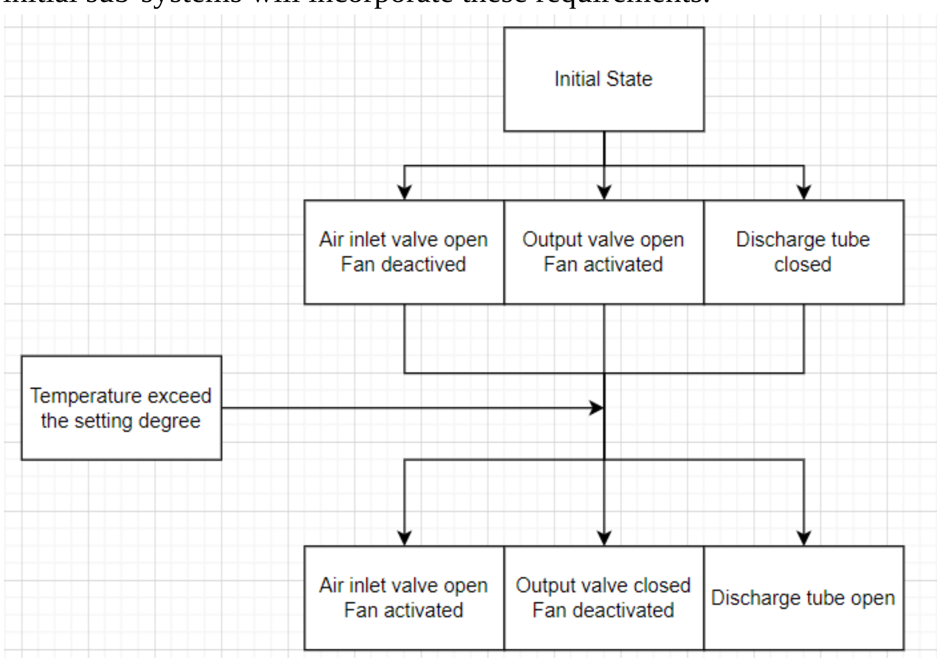


*Figure 1. Cooling Mechanism Flowchart*

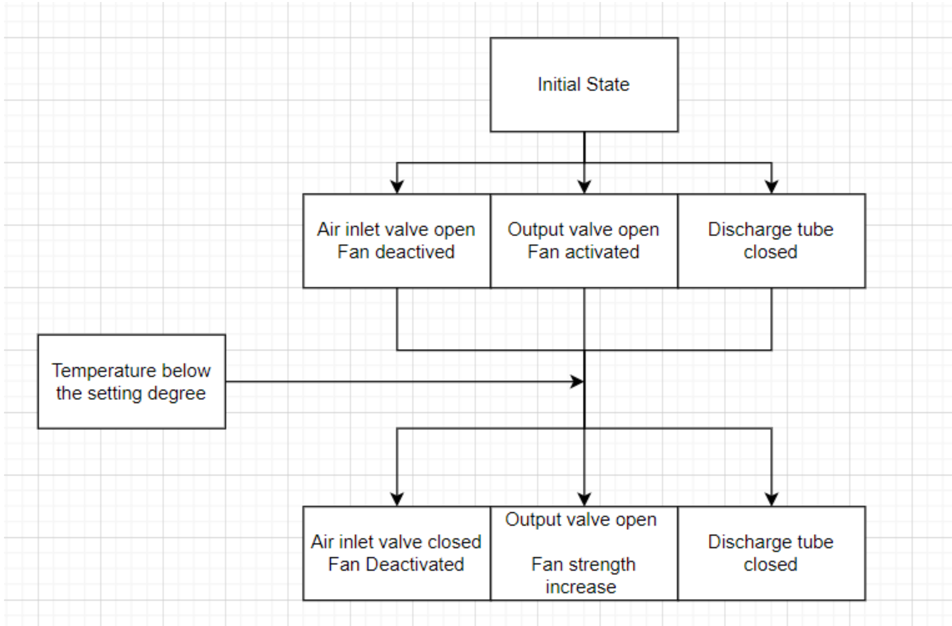


*Figure 2. Heating Mechanism Flowchart*

# 3 Team Concept Generation

## 3.1 Sub-System 1: Air Intake (Inlet) and Output (Fan)

### 3.1.1 Air gathering system - Kaiyi

For the tubes, the box should have 3 distinct tubes without valve for gathering heat from the ground, made of heat conducting materials with 10cm in radius each. For the inlet air tube, a valve is needed along with a fan to accelerate the process of mixing of air. A main output tube is needed as well to deliver the processed air into the house, the tube must be made of non-heat conducting material, it may branch according to the user's need. Furthermore, a fan along with a valve is necessary for the output tube, the filter should be filtering the air after they pass thought the valve. Also, a valved discharge tube connecting to the ground to release the exceeded air is necessary.

There are two types of air vents such as, supply vent and return vent.

- **Supply Vent**: blows conditioned air into indoor spaces
  - Smaller than return vent
  - Has louvers (behind grill) to direct air flow
- **Return Vent**: pull air out of indoor spaces to deliver to heating/cooling system
  - Larger in size
  - Does not have louvers

### 3.1.2 Fan - Fahima

For the air inlet fan, it is recommended to implement centrifugal fans because they are suitable for generating high-volume air. Two types of fans are used in HVAC systems, Axial and Centrifugal.

1. **Axial fans** have enclosed fan blades in a tube allowing for consistent airflow. This is useful for consistent cooling and uniform air volume output.
2. **Centrifugal fans** also can increase the volume of air and deliver high-pressure, high-volume air output.
    a) In this case, the product should be energy efficient so, applying a backward curved centrifugal fan is recommended because it consumes less power and generates less noise.
    b) A forward curved design indicates that the tip of the blade is forward curved, and this results in high pressure air output.
    c) When the blades are inclined then this implies that it has an airfoil design where these fans can generate high speed air output without creating a swirl. They also produce low noise and most optimal for HVAC that require active ventilation.

## 3.2 Sub-system 2: Piping Network and Sump Pump

### 3.2.1 Piping Network – Kayla

**Configuration**

There are various methods to configure a piping network for a geothermal heat pump system, however given the client's needs we will review each configuration and discuss the benefits and setbacks.

There are three piping layouts that will be considered for a horizontal configuration as they are the most cost-efficient configuration for residential installations and most suitable for residential installation. There are other configurations such as pond, lake and well configurations, however they will not be considered for this prototype because they require a large body of water which is not suitable for urban residential neighborhoods. There are also vertical configurations, but the pipes need to be buried a 100 to 400 feet underground which is not realistic for a residential system.

Horizontal Pipe Layouts:

- **Straight pipes buried at same depth**: Require a large amount of space.
- **Straight pipes buried at different depths**: Require a large amount of space and is exposed to a range to soil vertical temperature profiles.
- **Looped pipes (aka the Slinky method) buried at same depth**: Conserves space, is increasingly cost-efficient and is exposed to a range to soil vertical temperature profiles.

**Material**

The most used materials for geothermal heat pump systems are high-density polyethylene (HDPE) and crosslinked polyethylene (PEX). These materials are highly recommended due to their flexible yet durable material characteristics and lifespan of approximately 50 years.

HDPE is currently the preferred material because it is exceptionally reliable, has high chemical resistance, high pressure rating, no mechanical fittings and has the best thermal conductivity in comparison to other piping materials. Another consideration is that it is available for different pressure ratings and is easily obtainable.

PEX is a good alternative to HDPE since PEX has a higher thermal conductivity and shares similar desired properties with HDPE but the material costs twice the amount than its counterpart. So, the main consideration when selecting the material is the value of the system efficiency vs cost.

### 3.2.2 Sump Pump - Fahima

For this initial design, it requires a sump pump therefore, sump pumps are interchangeable making it more efficient by saving time and lowering cost. The sump pump can be installed outside so that it can relocate water during storms or floods. There are four types of sump pumps, pedestal sump pump, submersible sump pump, battery backup sump pump, and combination sump pump.

- **Pedestal Sump Pump**
    - Common choice for homes
    - Cheapest option
    - Ideal for smaller sump pits
    - Can run the risk of overheating because the motor can be cooled down since its mounted high on the rod, keeping it dry
- **Submersible Sump Pump**
    - Cost-effective choice because they have better performance and longer life span
    - Fully submerged in water
    - Motor is covered and enclosed in waterproof casing so, there is less chance of water damage
- **Battery Backup Sump Pump**
    - Useful for when power goes out
    - Powered by electric outlet
    - Can continuously pump water out for 12 hours
    - Cannot be used as main pump since it can only handle small rain events
- **Combination Sump Pump**
    - Combination of primary pump and battery back up
    - Protected under normal circumstance and when there’s a blackout

The check valve of the pump can be installed horizontally or vertically, however, it is more optimal if it’s installed horizontally when pumping out solid or semi-solids. The sump pump check valve tends to be designed as a flapper style where one valve is installed in the discharge pipe. By gravity the flapper closes when the pump is shut off.

## 3.3 Sub-system 3: Control System and Sensor

### 3.3.1 Control system – Kaiyi & Tareq

For the control system, a thermal sensor is necessary to measure the influx of heat relative to desired set temperature. When the desired temperature is met, the system would shut down via a final control element. The controller would have to be either a P-controller, PI-controller, or PID-controller. The P (proportional) aspect of controllers is the most commonly used method for reducing the errors of a system so that it would meet the desired set specifications, which is temperature in our case. The disadvantage of a PI-controller is that it never actually allows the system's error to reach zero error, for the difference between the current temperature and set one, and thus will only be "proportionally close" to the desired temperature and it isn't necessarily quick. PI-controllers allow for integral response which will always lead the error to become zero. Thus, using a PI-controller will allow our system to be at our desired temperature with zero error. The disadvantage of PI-controllers is that they are very slow to reach the desired set point. PD-controllers are very quick to reach the desired set point. PD-controllers' disadvantages are overshoots and the fact that it is extremely sensitive to noise that could lead it to reach incorrect set points, in our case different temperatures.

### 3.3.2 Sensors – Kayla and Kaiyi

For this system it is important to include sensors that hold specific roles. Sensors that would be essential include a temperature sensor and pressure sensor.

**Temperature Sensor**

A temperature sensor is a device that is used to measure temperature. For this project, we're specifically interested in using a thermocouple or resistance temperature detector (RTD):

- **Thermocouple**: Composed of two wires of different metals joined together at their ends. If the junctions are exposed to different temperatures, a voltage is produced which tells you the temperature. Thermocouples are cost effective however they are prone to error and inaccurate temperature readings
- **RTD:** Uses electrical resistance to measure temperature. They are very accurate in comparison to other temperature sensors however they are also the most accurate.

**Pressure Sensor**

Additionally, Pressure sensors are used to ensure systems operate correctly and efficiently. They measure the pressure of rooms and monitor the air flow. This can help our system optimize heating, air flow and reduce energy consumption. This sensor increases the efficiency of our design, it controls the operations of the system such as turning it on and off or closing valves and vents. This provides lower energy consumption and will result in a far more efficient system. It reduces operational costs significantly.

- **Capacitance Pressure Sensor**: Reliable durability, works in high temperature; but only measures compound pressure.

- **Micromachined Silicon (MMS) Pressure Sensor:** Measures low pressures in both absolute, compound, and gauge references.

### 3.3.3 Additional heat source – Kayla

**Solar Panel**

A solar panel can be installed above the ground, which will be connected to a thermal mass inside the box. The installation of the thermal mass makes the product able to further increase the maximum temperature. The limiting factor is that the output is dependent on the location and size of the solar panel.

**Hydronic Baseboard Heater**

Hydronic baseboard heaters are another viable option as they release no green-house gases and use an internal reservoir of heated liquid to produce radiant heat. The only issue is that one system does not provide sufficient energy to heat a building, so it may be beneficial to explore system modifications to increase efficiency.

## 3.4 Sub-system 4: Heat Exchange Chamber and Thermal Energy Storage

### 3.4.1 Heat Exchange Chamber - Mustafa

Heat exchangers function by transferring heat from one area to another. There are many different types and sizes of heat exchange chambers. Some of these include, shell and tube, double pipe plate heat exchangers and more.  Shell and tube exchangers are constructed of single tube or series of parallel tubes closed with a sealed cylindrical pressure vessel.  Double pipes employ the simplest heat exchanger design and configuration which consists of two or more concentric, cylindrical pipes.  Finally, plate heat exchangers are constructed of several thin pates stacked on top of each other. The shape that we will be using in our design will be a rectangular heat exchange chamber. The ideal material choices are clay and concrete. These materials are the most sufficient. The two most common materials used for heat exchangers are aluminum and copper. They are both cost-efficient and are highly effective. Other materials include bronze, titanium, carbon steel and more.

*Table 1. Benefit and Drawbacks for different materials of the heat exchange chamber*

| Material | Benefits | Drawbacks |
|---|---|---|
| **Clay** | • Does not absorb or retain much heat<br>• Can be easily shaped<br>• Increase of strength<br>• Reduction of plasticity<br>• Durable<br>• Reduces dust and allergens in air<br>• Absorbs odor | • Potential cracking |
| **Concrete** | • Warm and cools slowly | • Heavy Weight |

| | | |
|---|---|---|
| | • Stays warm/ cool for long period of time<br>• Delays and releases heat transfer through walls<br>• Reduces heat loss from buildings<br>• Highly durable and resilient<br>• Low maintenance<br>• Energy efficient<br>• Cost effective<br>• Can be recycled | |
| **Copper** | • Thermal conductivity<br>• Excellent conductor of heat<br>• Ease of inner grooving | • Venerable to corrosion<br>• Lower lifespan<br>• Due to corrosion, it loses efficiency |
| **Aluminum** | • Weight<br>• Performance<br>• Corrosion resistance<br>• Cleanability | • Doesn't transfer heat very well<br>• Rust<br>• Breaks down easily |

Furthermore, the thickness of the chamber affects heat transfer. The minimum thickness of a heat exchange chamber is 3mm. The rate of heat transfer is inversely proportional to thickness.

### 3.4.2 Thermal Energy Storage – Mustafa

This heating device requires thermal storage. Thermal energy storage is achieved with a wide variety of different technological devices. These technologies allow excess thermal energy to be stored and used months later at scales ranging from building, district, town, or region. It also allows heat to be transferred and stored. A thermal storage is like a battery for a building's air conditioning/heating system. This method is built into new technologies that complement energy solutions such as solar and hydro. Different types of materials include metals, concrete, rocks, sand, and bricks. These can be utilized by both higher and lower temperature energy storage because they will not boil or freeze.

*Table 2. Benefit and Drawbacks to different type of materials for thermal energy storage*

| Materials | Benefits | Drawbacks |
|---|---|---|
| **Brick** | • Good for storing energy<br>• Can be converted into energy | • Difficult to mold into desirable shapes |
| **Clay** | • Good for storing energy<br>• Low cost<br>• Unique structure<br>• Abundant<br>• Environmentally benign | • Lower stress threshold than other material. |

| | | |
|---|---|---|
| **Sand** | • Store up to 26,000 megawatt hours of thermal energy<br>• Eco friendly | • Limited to a Rankine cycle for energy transfer |

## 4 Conceptual Design

*Table 3. Listing various solutions for the different components of the sub-systems*

| Sub-System | Components | Team Member Generated Solutions |
|---|---|---|
| 1 | Air Inlet | • Supply Vent<br>• Return Vent |
| | Fan | • Axial<br>• Centrifugal |
| 2 | Piping Network Configuration | • Straight pipes buried at same depth<br>• Straight pipes buried at different depths<br>• Looped pipes (aka the Slinky method) buried at same depth |
| | Pipe Material | • high-density polyethylene<br>• crosslinked polyethylene |
| | Sump Pump | • Pedestal sump pump<br>• Submersible sump pump<br>• Battery backup sump pump<br>• Combination sump pump |
| 3 | Control System | • P-Controller<br>• PI-Controller<br>• PID-Controller |
| | Temperature sensor | • Thermocouple<br>• RTD |
| | Pressure sensor | • Capacitance Pressure Sensor<br>• MMS Pressure Sensor |
| | Additional Heat Source (optional) | • Solar panel with a heater<br>• Hydronic baseboard heater connected into the box |
| 4 | Heat Exchange Chamber | • Clay<br>• Concrete<br>• Sopper Aluminum |
| | Thermal Energy Storage | • Brick<br>• Clay<br>• Sand |

# 5 Refined Design Concepts

From each sub-system, there are correlating components that were incorporated in the three design concepts. For instance, Design Concept 1 focused on which type of component was the cheapest while Design Concept 2 was fixated on the most efficient component and lastly Design Concept 3 determined the most optimal components needed for our prototype.

*Table 4. Comparing different components for each design concept and determining the most suitable component for each design based on certain criteria*

| **Sub-System** | **Components** | **Design Concept** | | |
|---|---|---|---|---|
| | | **1** | **2** | **3** |
| 1 | Air Inlet | Supply | Return | Return |
| | Fan | Axial | Centrifugal | Centrifugal |
| 2 | Piping Network Configuration | Straight pipes buried at different depths | Looped pipes buried at the same depth | Looped pipes buried at the same depth |
| | Pipe Material | high-density polyethylene | crosslinked polyethylene | high-density polyethylene |
| | Sump Pump | Pedestal Sump Pump | Combination Sump Pump | Submersible Sump Pump |
| 3 | Control System | PI-Controller | PI-Controller | PI-Controller |
| | Pressure Sensor | Capacitance | MMS | MMS |
| | Temperature Sensor | Thermocouple | RTD | RTD |
| | Additional Heat Source (optional) | N/A | Solar panel with a heater | N/A |
| 4 | Heat Exchange Chamber | Clay/Concrete | Clay/Concrete | Clay/Concrete |
| | Thermal Energy Storage | Sand | Brick | Sand |

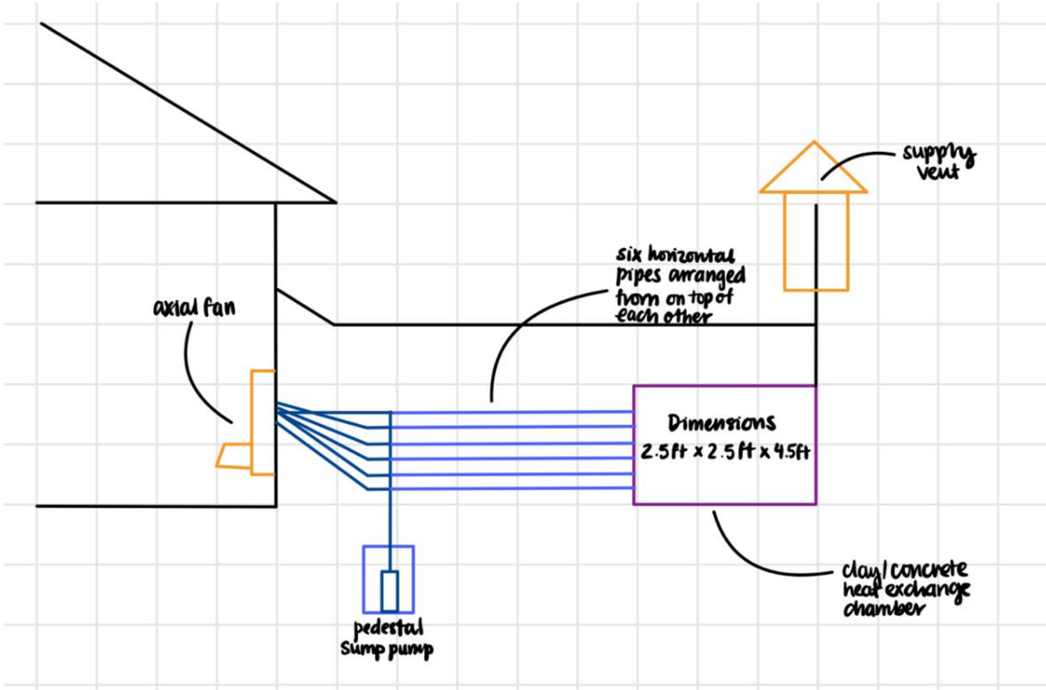


*Figure 3. Design Concept 1*

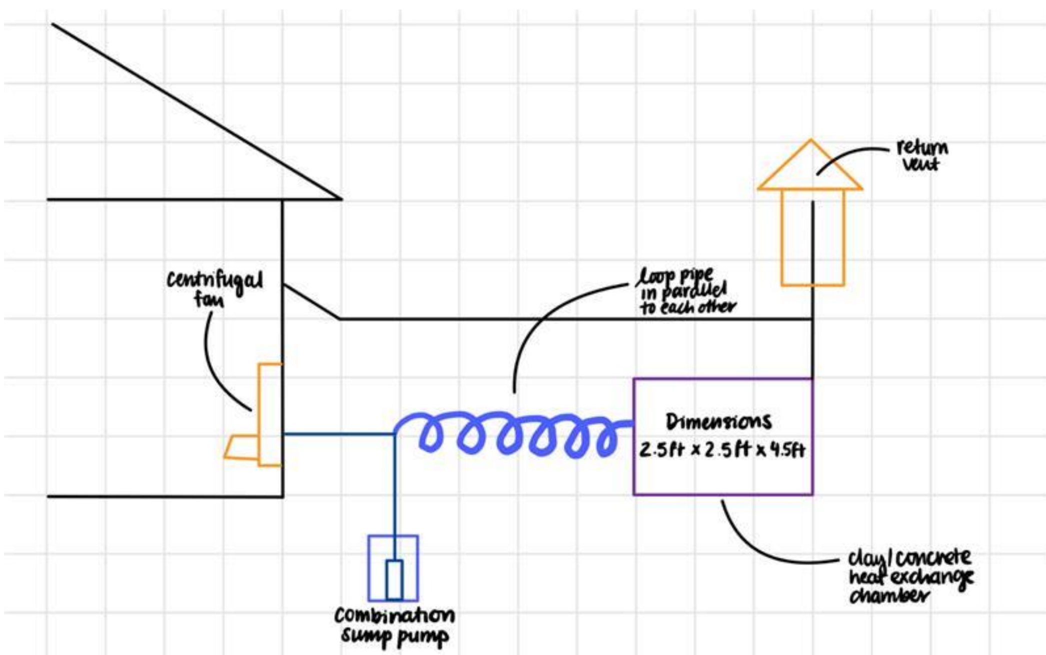


*Figure 4. Design Concept 2*

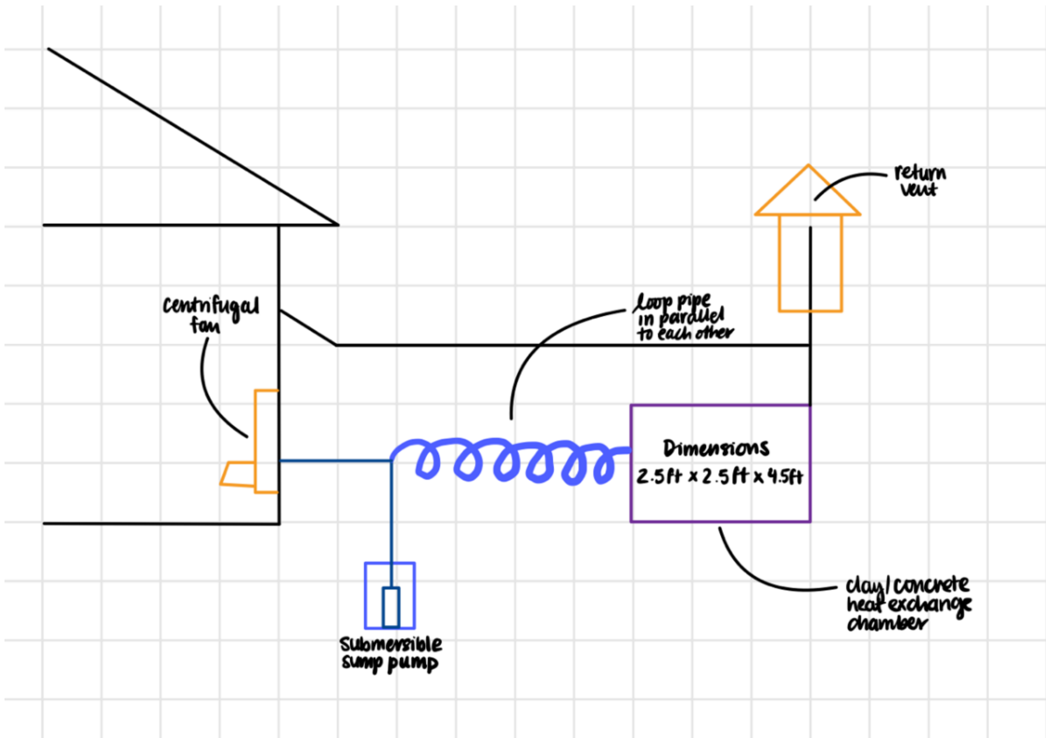


*Figure 5. Design Concept 3*

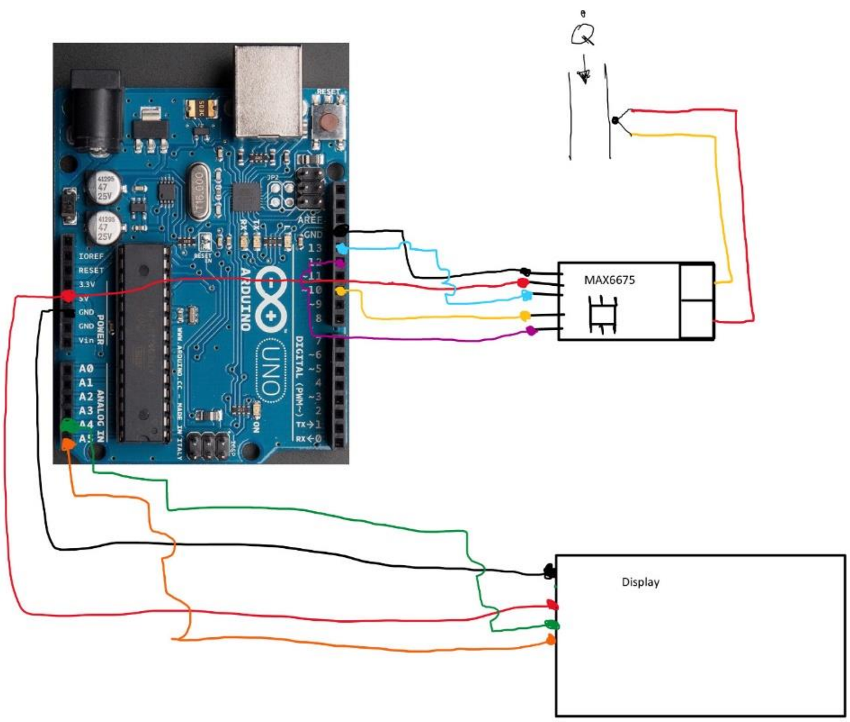


*Figure 6. Thermocouple connected to inlet pipe and to Arduino controller with display*

*Table 5. Benchmarking for the Three Design Concepts*

| DC / Specifications | Design Concept 1 | Design Concept 2 | Design Concept 3 |
|---|---|---|---|
| Item Weight | 23 lbs | 30 lbs | 24 lbs |
| Portability | Yes | Yes | Yes |
| Dimensions | 28.125 square feet | 28.125 square feet | 28.125 square feet |
| Energy Intake System | Draws energy from earth via pipes. | Draws energy from earth via pipes and draws extra solar energy. | Draws energy from earth via pipes. |
| Limiting factor | The temperature is limited due to insufficient energies | budget is insufficient for this solution | The temperature is limited due to insufficient energies |
| Infrastructure required | Yes | Yes | Yes |
| Equipment Cost | $50 | $150 | $85 |
| Operational Cost / month | $20-40 | $20 / sq ft | $45-95 |
| Temperature manipulation (°C) | 15-20 | 15-30 | 15-22 |
| No greenhouse gas emission | No | No | No |
| Safety / Dependability (1-5 scale: 5 as the highest level) | 3 | 4 | 5 |

*Table 6. Design Matrix for the Three Design Concepts*

| HVAC System / Specifications | Importance (weight) | Design Concept 1 | Design Concept 2 | Design Concept 3 |
|---|---|---|---|---|
| Item Weight | 3 | 3 | 1 | 2 |
| Portability | 3 | 3 | 3 | 3 |
| Dimensions | 5 | 3 | 3 | 3 |
| Energy Intake System | 1 | 2 | 3 | 2 |
| Limiting factor | 5 | 1 | 2 | 2 |
| Infrastructure Required | 5 | 3 | 3 | 3 |
| Equipment Cost | 3 | 3 | 1 | 2 |
| Operational Cost | 5 | 2 | 2 | 2 |

| | | | | |
|---|---|---|---|---|
| Temperature manipulation | 3 | 1 | 2 | 1 |
| No greenhouse gas emission | 4 | 3 | 3 | 3 |
| Safety/dependability | 5 | 1 | 2 | 3 |
| Total | | 94 | 96 | 103 |

Note: The design specifications are ranked on a scale of 1-3 (3=green, 2=yellow, 1=red). 3 being the "best" and 1 being the "worst". The ranking of each specification will depend on user needs. After determining the best specifications, multiply the importance of weight by its value (1-3}.

Based on our design matrix, we found that the third design concept met majority of our design specifications and we would like to use this to develop our prototype.

# 6 Conclusion and Recommendations for Future Work

In the solution generating process, we have learned to generate ideas in both vertical and lateral directions, and solved problems with different approaches and techniques. The brainstorming was successful, and in the first stages no ideas were left out. Upon further refinement, more solutions were eliminated. Together, our team generated three solutions and narrowed it down to one upon further analysis. According to the information we gathered from the client interview, the matrix created based on the demands and the requirements of clients, including the function of our product from user's perspective.

Following the conceptual design process involving the definition of subsystems and potential solutions for these subsystems three unique global solutions that fulfilled all the defined criteria were developed and explained. Solution analysis led to identifying that the only difference between the solutions came down to cost and what was more tailored to the request of the client.

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